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Measuring the effects of energy transition: A structural decomposition analysis of the change in renewable energy use between 2000 and 2014

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HIGHLIGHTS

- The contributors to the change in global renewable energy use are analyzed.
- A new variant of a structural decomposition analysis introduces energy transition.
- Energy transition contributed little to the change in global renewable energy use.
- Also the global effects of changes in trade structure are very small.
- Affluence, population growth and technology changes are the main contributors.

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ABSTRACT

This study investigates the growth in global renewable energy use between 2000 and 2014. To identify its main contributors and their geographical distribution, a structural decomposition analysis is applied to global multi-regional input-output tables. A new variant of this type of analysis is developed that introduces energy transition (i.e. the substitution of non-renewable energy by renewable energy) as one of the contributors. Global renewable energy use rose by 22.1 Exa Joules (EJ), from 57.8 EJ in 2000 to 79.9 in 2014. The contribution of energy transition at the global level to this 22.1 EJ increase was small and positive (+1.3 EJ). As for the geographical distribution of the effects, positive effects are found for the European Union and the United States, negative effects for China, India, and the Rest of the World (which includes many developing and emerging countries). Trade structure changes also had a small effect on global renewable energy use (+1.1 EJ). The main contributions were the worldwide changes in: technology and overall energy efficiency (−23.6 EJ); consumption per capita (+32.2EJ); and population (+11.0 EJ).

1. Introduction

Global warming and climate change are amongst the most serious concerns and threats to countries all over the world. At the UNFCCC's 21st Conference of Parties (COP21) held in Paris in 2015, countries agreed to aim at "holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" [1, Article 2]. Reducing or nullifying anthropogenic greenhouse-gas (GHG) emissions is absolutely necessary for this. However, when compared to other environmental pressures, a typical characteristic of global warming is that it is primarily an energy problem. International Energy Agency [2] and European Commission [3] highlight that energy production and consumption are responsible for approximately two-thirds of the world's GHG emissions. This is because energy production and consumption are largely based on the combustion of fossil fuels (mainly oil, coal, and natural gas). This combustion releases CO_2 in the atmosphere which in turn is the principal component of the GHGs causing global warming. Thus energy use and climate change are two sides of the same coin.

According to the EDGAR 4.2 database [4], the total amount of CO_2 emissions in 2014 was 35.7 Gigatonnes (Gt) and 29.7Gt was only due to fossil fuel combustion. In its turn, 78% of global energy consumption in 2014 is from fossil fuel combustion. The remaining shares are 19% for renewable energy and 3% for nuclear energy [5,6]. Energy transition, i.e. the shift from non-renewable to renewable sources of energy, has been put forward as an answer to global warming. For example, IPCC

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[7] suggests the implementation of country-specific policies promoting energy transition. Although renewable energy (RE hereafter) is neither 100% GHG free nor completely free from any other type of environmental stress, it is unquestionably much less GHG intensive. This justifies the political effort in speeding up the energy transition (as already pointed out in [8]).

However, the actions for climate change (or any environmental issue in general) may collide with other development goals. For example, improving living standards or increasing income per capita in developing countries is likely to raise energy use and foster population growth. This will induce a further rise in energy demand and, consequently, in environmental pressures [9]. The United Nations 2030 Agenda for Sustainable Development [10] tries to bridge such contradictions by reformulating goals with a sustainability twist, ensuring a more integrated approach. By addressing energy issues (Goal 7) and other challenges brought by globalization (such as production fragmentation and technological innovation), this integrated approach aims to balance material and social gains (Goals 8 and 12) with environmental stress.[1]

To further develop plans or actions to enhance energy transition, it is necessary to be able to measure its effects. Not only *ex post* measurement of past performance but also *ex ante* measurement of expected or anticipated changes. The key questions in this paper are: What are the variables that contribute to (or, following the input-output literature, what are the "drivers of") the changes in renewable energy use and what is the role of energy transition?

Answering these questions is non-trivial because several forces are at work and not all forces work in the same direction. To illustrate this point, suppose it would be found that RE use has increased in the last couple of years by 2 Exa Joules (EJ). In itself a very minor change (2.5% of the 2014 level). However, this would be an enormous achievement if it were caused by a −48 EJ change due to gains in energy use in general and a +50 EJ change due to energy transition. In contrast, it would be an utter failure if it were caused by less efficient use of energy (leading to +50 EJ of RE use) and reversed transition (i.e. substitution from RE to non-RE leading to a change in RE use of −48 EJ).

The first question (What are the drivers of the changes in RE use?) is answered by applying a structural decomposition analysis (SDA). SDAs have been developed in the field of input-output (IO) analysis and are commonly applied for questions about quantifying the effects of changes in the drivers of a certain phenomenon (like global energy use, or territorial emissions). Specifically, this paper will adapt the approach used in Arto and Dietzenbacher [11] and Xu and Dietzenbacher [12]. The idea of an SDA is to split the change in the variable that is to be explained (in this paper: global renewable energy use) into the effects induced by the change in each of the drivers (i.e. explanatory variables, such as consumption per capita). The contribution of the driver then reflects the change in global RE use if only this driver (e.g. consumption per capita) had changed as it actually has changed and everything else had remained the same (i.e. using the *ceteris paribus* clause that is commonly applied in economics).

None of the existing SDAs includes energy transition as one of the drivers. To answer the second question (What is the role of energy transition?) therefore requires a new SDA variant that singles out the effect of changes in energy transition. This is done by adding one extra step to an SDA of total energy use. The extra step consists in expressing RE use as the multiplication of total energy use with the RE share (in total energy use). An increase in the RE share then reflects energy transition.

Summarizing, this paper studies the development over time of RE use. It asks what has driven the changes in RE use and how large was the change caused by each driver? Because of its policy relevance, this paper chooses to introduce energy transition as one of the drivers of the changes in RE use. To quantify the contributions of the drivers to changes in RE use, a structural decomposition analysis is applied annually to the world input-output tables from WIOD for the period 2000–2014.

[1] Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all; Goal 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all; Goal 12: Ensure sustainable consumption and production patterns.

2. Methodology and data

2.1. Structural decomposition analysis

Structural decomposition analysis (SDA) is a tool that is frequently used by researchers to quantify what drives a certain phenomenon (see [13], for a review of methods). In its simplest form, SDA starts from an identity where one variable depends on two determinants (i.e. the drivers). Say, $\alpha = \beta\gamma$ where α, β, γ are matrices, vectors, or scalars. α is the variable whose development over time is driven by (or determined by) the changes in β and γ. For all variables, data are available for two points in time, say year 0 and year 1. The change in α can then be expressed as:

$$\alpha_1 - \alpha_0 = (\beta_1 - \beta_0)\gamma_1 + \beta_0(\gamma_1 - \gamma_0) \tag{1a}$$

$$= (\beta_1 - \beta_0)\gamma_0 + \beta_1(\gamma_1 - \gamma_0) \tag{1b}$$

$$= \frac{1}{2}(\beta_1 - \beta_0)(\gamma_0 + \gamma_1) + \frac{1}{2}(\beta_0 + \beta_1)(\gamma_1 - \gamma_0) \tag{1c}$$

The first term on the right hand side gives the contribution of the changes in β to the changes in α. It measures how much α would have changed in case β had changed as it actually has and all other variables (in this example only γ) would remain unchanged. Equations (1) indicate that the decomposition of the changes in α into the changes of its determinants is not unique. Typically, in actual applications (1c) is used, as it is the average of (1a) and (1b). Further details on SDA are given in Appendix A.

SDA has been applied to a wide range of topics. These include describing the change in environmental pressures (e.g. [14], consider Beijing's water footprint and [15,16], consider socio-economic drivers of environmental pressures) and the growth in energy or resource use. As mentioned above, SDA starts from an identity. Standard in the literature is to take the identity corresponding to the demand-driven input-output model. One of the drivers is then household consumption. However, the researcher may wish to make the SDA somewhat more complex in order to highlight a variable that is of particular interest. Household consumption may thus be split into consumption per capita and population. The SDA then calculates the contribution of each driver (e.g. consumption per capita, which is also one of them in this paper) to the change in the variable of interest (in this paper global renewable energy use).

Many studies have applied SDA to find the drivers of the growth in emissions or energy use. Originally, the analyses were at the national level, later also at other levels. Examples at the national level include: the SDAs of energy use by Lin and Polenske [17] for China, by Wachsmann et al. [18] for Brazil, and by Weber [19] for the US; the SDA of energy intensity by Alcàntara and Duarte [20] for European member states; the SDA of net energy consumption for Australia by He et al. [21]; the SDAs of CO_2 emissions by Lim et al. [22] for Korea, by Baiocchi and Minx [23] for the UK, by Feng et al. [24] for the US, and by Peters et al. [25] and Minx et al. [26] for China. See Yuan et al. [27] for an SDA at the regional level to study residential indirect CO_2 emissions in Chinese regions and Hu et al. [28] for an SDA of GHG emissions in Chongqing (i.e. an analysis at the municipality level).

However, CO_2 and GHG emissions are global pollutants and therefore require an analysis at the global level. Besides, international fragmentation has led to an enormous increase in trade. According to

Arto and Dietzenbacher [11], world trade tripled from 6.3 trillion US$ (21% of world GDP) in 1995 to 19.5 trillion US$ (32% of world GDP) in 2008. As a consequence, also the trade in emissions increased. For example, Peters et al. [29] reported that the CO_2 emissions embodied in the production of traded goods and services increased from 20% of global emissions in 1990 to 26% in 2008. Using different databases and different pollutants, Arto et al. [30] and Xu and Dietzenbacher [12] arrive at similar results.

These developments in the 1990s and 2000s implied a rising need for SDAs that fully cover international trade. For a long time, the techniques to carry out an SDA at the global level were well known (see e.g. [31,32,33], for SDAs in a multi-country—but not global—setting), but appropriate data were not available. Recently, however, several global multiregional input–output (GMRIO) tables have been constructed (see [34], for an overview). SDAs at the global level have thus become a well-known and widely used tool (see for example [35], for global CO_2 emissions and [36], for global energy footprints).

The SDA in this paper starts from the global-level SDAs in Arto and Dietzenbacher [11] and Xu and Dietzenbacher [12]. That is, the change in global RE use is driven by changes in consumption per capita, population changes, and technology changes. These technology changes include the changes in the intensity of RE use (i.e. use per dollar of production). The second research question, however, focused on the role of energy transition. Instead of using "intensity of RE use" as a single contributing variable in the SDA, this article splits that variable further. That is, "intensity of RE use" is the product of "intensity of *total* energy use" and "the share of RE use in *total* energy use". All in all, the change in global RE use is driven by (amongst other variables) the change in the intensity of RE use, which in itself is driven by the change in the intensity of total energy use and the change in the share of RE use in total energy use.

The drivers that will be used in this paper are:

- technology changes, which include changes in the input of total energy use in production per unit of output, the changes in the shares of energy directly used by households in total consumption, and the changes in intermediate input use per unit of output;
- changes in trade structure, which include changes in the import shares of intermediate inputs, and changes in the import shares of final products;
- changes in the final demands ("consumption") per capita;
- changes in population;
- changes in energy transition, which includes changes in the share of renewable energy use in total energy use for the production processes, and changes in the share of renewable energy use in total energy use for the energy directly used by households.

A full description of the methodology (including all technical details using mathematical formulation) is given in Appendix A.

2.2. Data sources

Several groups of researchers constructed sets of global multiregional input–output (GMRIO) tables (examples are WIOD, [37], Exiobase, [38], EORA, [39], GRAM, [40], GTAP, [41]. Clearly, these GMRIO databases differ, in terms of country coverage, industry detail, time period, focus (e.g. socio-economic or environmental), or construction principles (see [34], for an overview). Therefore, various studies have been carried out comparing the outcomes obtained with different databases [42,43,44,45,46,47]. The overall conclusion of that research is that the differences are generally small when the results are considered at the global level and when the results are in terms of percentage contributions.

The analysis in this article will be based on the tables from the World Input-Output Database (WIOD, see [37,48], all data can be downloaded free of charge at www.wiod.org). In particular, IO tables from the 2016 release of the WIOD will be linked to energy use data from Kulionis [49] to carry out an SDA of global RE use change during the period 2000–2014. The WIOD tables in the 2016 release contain 44 countries: 28 EU members states; fifteen other major economies (Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Norway, Russia, South Korea, Switzerland, Taiwan, Turkey, the United States); and the Rest of the World (RoW) aggregate. The tables are based on data for 56 industries and products that are classified according to the International Standard Industrial Classification revision 4 (ISIC Rev. 4). The tables are in line with the SNA 2008. Note that the WIOD 2016 release does not contain data on energy use.

Energy use in Tera Joules (TJ) that matches the WIOD classification (in terms of years, countries, and industries) is obtained from Kulionis [49]. These data record 26 different energy carriers and are in line with the WIOD data for 1995–2009 in the environmental satellite accounts of the 2013 release (see [50]. The present study, however, focuses on RE sources only. According to reports by IEA [6] and REN21 [5], the energy commodities that come from renewable sources are: biogas, biogasoline, biodiesel, geothermal heat (geoheat), waste combustion (waste), solar, wind, hydroelectric energy (hydro), and a category labeled "other renewables" (other). The WIOD energy flows and commodities are more aggregated than the IEA energy classification. Tables B1 and B2 in Appendix B provide an overview of the correspondence.

The results in the next section are presented in terms of regional aggregates. Distinguished are: EUR, which refers to European countries (i.e. the EU28 plus Switzerland and Norway); East Asia (EAS), which includes Japan, South Korea and Taiwan; China (CHN); Indonesia (IDN); India (IND); Brazil (BRA); Russia (RUS); the USA; the RoW; Canada (CAN); Mexico (MEX); Australia (AUS); and Turkey (TUR). Population data, needed for the per capita calculations, were gathered from the World Bank (WB) database (see http://data.worldbank.org). Since population time series for Taiwan are not available in the WB dataset, they were retrieved directly from the Taiwanese National Statistical Agency (see http://eng.stat.gov.tw).

2.3. Deflation and chaining the results

One of the reasons to use the tables from WIOD is that it provides GMRIO tables in constant prices (namely in prices of the previous year). Because energy use is measured in physical quantities (Tera Joules, TJ = 10^{12} J) and the IO tables are in money terms (millions of US dollars), results may in general be confounded by price effects. Price effects emerge if data in money terms are linked to data in physical terms, as is the case in this paper for the energy input coefficients (in TJ per million USD). To sketch the consequences of price effects, consider the following example. Suppose that nothing happens in physical terms (neither final demands, nor production, nor energy use), but all prices increase by 10%. In that circumstance the value of the outputs as measured in the IO tables will also increase by 10%. All energy input coefficients will therefore decrease by 1/11 (=9%). The decreased energy input coefficients suggest that the countries have become more energy efficient, whereas physically speaking nothing has changed. Therefore the IO tables need to be deflated to avoid such "price biases".

Whilst IO tables in constant prices do exist at the national level, they do not exist at the global level. A standard problem of deflating IO tables occurs if the year under consideration is far apart from the base year. The base year basket of goods is not very representative of the basket of goods that is consumed or produced in the year under consideration. The values in constant prices may in that case be biased. Traditionally, IO tables are constructed with the double deflation method. A disadvantage of this method is that all biases cumulate in the value added in constant prices (see [51–52]. Therefore, it is not recommended to apply double deflation when a country changes considerably over a longer time period (2000–2014).

Instead, this study uses tables in prices of last year (i.e. previous year's prices, PYP). By doing so, the effects of price changes are

Table 1
Overview of energy use and changes therein, 2000–2014.

	RE Households		RE Production		Total RE		All energy
	EJ	% of RE	EJ	% of RE	EJ	% of all	EJ
2000	31.8	54.9	26.1	45.1	57.8	9.5	608.2
2014	36.8	46.0	43.2	54.0	79.9	10.2	780.1
Change	5.0	−8.9	17.1	8.9	22.1	0.7	172.5
	Average annual growth rates (%)						
	RE Households		RE Production		Total RE		All energy
2000–2007	1.4		3.0		2.1		2.4
2007–2014	0.7		4.4		2.5		1.2
2000–2014	1.1		3.7		2.3		1.8

Notes: RE Households = Renewable energy directly used by households, RE Production = Renewable energy used in the production process, Total RE = RE Households + RE Production, All energy = Total RE + all non-renewable energy, % of RE = taken as percentage of Total RE, % of all = taken as percentage of all energy, Change = difference in EJ between 2000 and 2014 or difference in percentage points.

discarded, thus leaving only the effects of the pure volume changes. These are the volume changes between this year (t) and last year (t-1). In the same fashion, the analysis yields the effects of volume changes between next year ($t + 1$) and this year (t). Chaining the results means that the effects are added, which yields the effects of the volume changes between next year ($t + 1$) and last year ($t - 1$). This is the so-called "chaining technique" proposed in de Haan [53]. Again, technical details can be found in Appendix A.

3. Results

3.1. Global trends of renewable energy use

The overview in Table 1, shows that energy use increased between 2000 and 2014 by 172.5 EJ (28.4%) implying an average annual growth of 1.8%. The share of RE remained more or less the same, approximately 10% of all energy. The marginal increase (of 0.7 percentage point) indicates though that energy transition has been modest in that period. RE use grew on average 2.3% per year, but RE used by industries in production grew much faster (3.7%) than RE used directly by households (1.1%). As a consequence, the share of RE use that is attributable to households dropped from 54.9% in 2000 to 46.0% in 2008.

The bottom panel of Table 1 shows that the divergence between households' RE use and production's RE use became stronger after 2007. The average annual growth of RE use increased from 2.1% in the period 2000–2007 to 2.5% in the period 2007–2014. The difference between the first and the second sub-period is positive for the use of renewable energy by industries (3.0% per year on average in 2000–2007 and 4.4% in 2007–2014) but negative for households (1.4% per year on average in 2000–2007 and 0.7% in 2007–2014).

The descriptive statistics indicate that in the period 2000–2014 RE contributed a modest part (approximately 10%) to the use of energy in general. The development of RE use only started to take off around 2007. The annual growth rates for energy use became larger for RE than those for non-renewable energy (fossil fuels and nuclear energy). This development was in particular due to industries using more RE. The full set of annual results is available from the authors upon request.

When focusing on RE sources in Table 2, the WIOD data show that biofuel (diesel, gasoline, and gas), solar and wind energy have a very small share of total RE use (2.0%) in 2000. In 2014, however, they provide together 10.4% of the total RE use. Hydroelectric energy and other renewables exhibit large, but declining, shares (together 92.1% of total RE use in 2000 and 82.8% in 2014). The third most used energy source is geothermal heat (with an average global share of 3.7% of total RE use in 2000 and 3.6% in 2014). The WIOD figures are in line with those reported in IEA [6] and REN21 [5], which additionally reports that between 2004 and 2009 on average 35.5 and 50.8 billion USD per

Table 2
Overview of the different sources of RE use, 2000 and 2014 (in PJ).

	RE Production				RE Households			
	2000		2014		2000		2014	
	PJ	%	PJ	%	PJ	%	PJ	%
Biodiesel	13	0	210	0	6	0	73	0
Biogas	220	1	915	2	77	0	429	1
Biogasoline	296	1	1647	4	192	1	642	2
Geoheat	2075	8	2651	6	94	0	253	1
Hydro	10,076	39	14,738	34	178	1	257	1
Solar	14	0	737	2	199	1	1099	3
Wind	118	0	2493	6	2	0	41	0
Waste	1141	4	2330	5	145	0	247	1
Other	12,137	47	17,458	40	30,861	97	33,717	92
Total	26,089	100	43,178	100	31,753	100	36,759	100

Notes: All numbers in Peta Joules (PJ) = 10^{15} Joules = EJ/1000, RE Production = Renewable energy used in the production process, RE Households = Renewable energy directly used by households, Geoheat = geothermal heat, Hydro = hydroelectric energy, Waste = waste combustion, and Other = other renewables.

year have been spent on new investments in solar and wind technologies, respectively. This reflects the political and policy attention given in the last decades to ecological issues and explains the boom in solar and wind energy use.

3.2. Drivers of renewable energy use at the global level

The research questions in this paper were: What are the drivers of the changes in renewable energy use and what is the role of energy transition? Fig. 1 cumulatively tracks the annual change in global RE use between 2000 and 2014 and the effects due to changes in the drivers. The analysis involves the computation of the five drivers listed in Section 2.

The use of RE increased by 22.1 EJ and the major contributors were: the growth in final demand (consumption) per capita (+32.2 EJ) and population growth (+11.0 EJ). The contribution of changes in the per capita consumption can be further split into changes in the *total* consumption per capita and the effects from changes in the commodity mix of the consumption bundle. The effects from commodity mix changes, however, turned out to be negligible (−0.5 EJ).

If all other things had remained unchanged, changes in just consumption would have almost doubled the change in RE use. In contrast, technology changes have largely decreased RE use (−23.6 EJ). To a large extent this is due to a reduction in energy intensities, which reflects the efforts of policy-makers in promoting more efficient means of

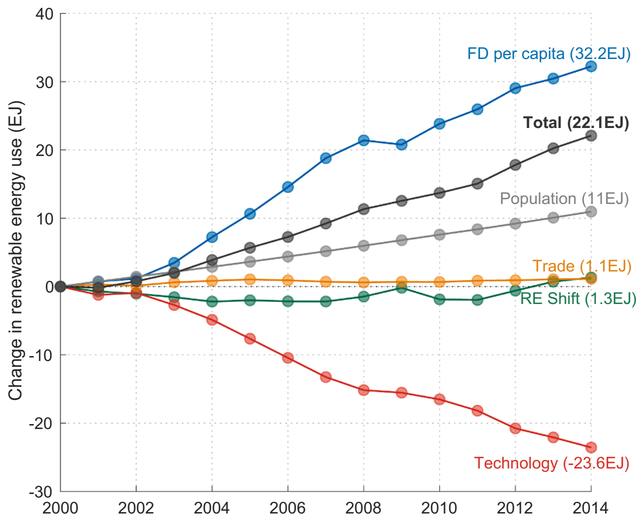

Fig. 1. Cumulative change in global renewable energy use by driver, 2000–2014 in previous year's prices. *Notes*: **FD per capita** consists of changes in the total final demand per capita (Δ**d**) and changes in the commodity mix of the consumption bundle (Δ**G**). **Population** represents changes in population (Δ**p**). **Trade** gives the effects of changes in the trade structure, which includes changes in the import shares of intermediate inputs (Δ**H**) and changes in the import shares of final products (Δ**T**). **RE shift** includes changes in the share of renewable energy use in total energy use (Δ**M**) for the production processes and changes in the share of renewable energy use in total energy use (Δ**u**) for the energy directly used by households. **Technology** effect consist of changes in the input coefficients for total energy use ($\Delta\bar{\mathbf{Q}}$), changes in technology coefficients (Δ**B**), and changes in the shares of energy directly used by households in total consumption ($\Delta\hat{\mathbf{w}}$).

production. In the period 2000–2014, the contributions of growth in consumption per capita and of technology changes grew steadily, except for the setback in 2009 (which was probably due to the global financial crisis).

The contribution of energy transition was modest in the period 2000–2014, if RE use is considered at the global level. It became already clear from the figures in Table 1 that there was a marginal shift in energy use from non-RE to RE. Its impact was a very small positive contribution (+1.3 EJ) to global RE use, if nothing else would have changed.

Changes in trade structure were also very small (+1.1EJ), which is quite surprising. As noted in Arto and Dietzenbacher [11], world trade tripled between 1995 and 2008 from $6.3 trillion (21% of world GDP) to $19.5 trillion (32% of world GDP). Yet, trade had little impact on growth of global RE use. The intuition behind the small effect is twofold. First, it matters what people consume, much less where it is produced or where the inputs (and the inputs into the inputs, etc.) are produced. Second, imports and exports of RE cancel each other out to a large extent. In other words, exports substitute RE use that otherwise would have taken place abroad and, similarly, imports substitute RE use that otherwise would have taken place locally. Trade in energy happened a lot and is important at the country level where it plays a role in the relocation of energy use. International trade appears to be a tool for countries to displace RE use to other locations rather than an important driver of RE use changes. A similar outcome was also reported by Arto and Dietzenbacher [11] for CO_2 emissions. Policy-makers and environmental organizations have viewed trade as one of the main culprits for environmental pressure. The findings of this paper unveil that trade plays only a limited (if not negligible) role and suggest that the standard view that trade is a major contributor to environmental problems might be somewhat exaggerated.

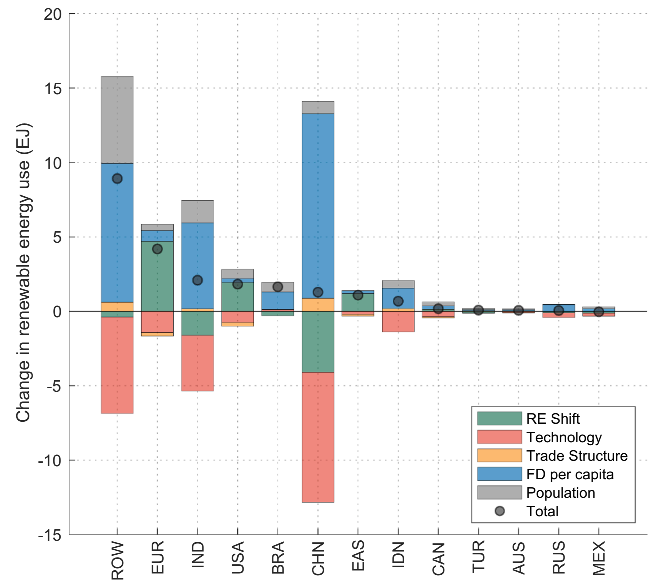

Fig. 2. Changes in territorial RE use by country and the contributions by global driving forces. *Notes*: See the notes to Fig. 1 for an explanation of the effects.

3.3. Drivers of renewable energy use at the country level

Fig. 2 shows the changes in territorial RE use between 2000 and 2014 at the country level and distinguishing the same five drivers. Consider, for example, China. Its territorial RE use increased by +1.3 EJ, which is indicated in Fig. 2 by the dot in the bar for China. It gives the "net" result of the positive and negative contributions of the drivers to China's territorial RE use. It appears that *global* changes in final demand per capita (i.e. changes in all countries are included) rose Chinese territorial RE use by +12.4 EJ. This was largely cancelled out by a global efficiency improvement which decreased China's territorial RE use by −8.7 EJ.

A remarkable finding is the growing importance of the RoW, which consists mostly of developing and emerging countries. Its territorial RE use increased by +8.9 EJ. The major drivers for this change were global affluence (contributing +9.3 EJ), global population growth (+5.9 EJ), and global changes in technology (−6.5EJ). Although these drivers are global, the largest part of the effect stems from "domestic" changes (i.e. in the RoW itself).

In the previous subsection, it was stressed that global RE use increased somewhat due to energy transition. Fig. 2 shows that the role of transition differs over the countries. It had a strong positive influence on RE use in the European countries (EUR, i.e. the EU28 plus Switzerland and Norway) and a small positive contribution in the US and East Asia. The results reflect the commitment of these economies to reduce their environmental pressure by promoting production processes that rely more on RE. In contrast, global transition had considerable negative impacts on the territorial RE use in China, India and the RoW, due to decreasing shares of RE in total energy use. It should be noted that this does not imply that transition has reversed (i.e. changed from renewable to non-renewable). Rather, it expresses that RE use grew less than non-RE use.

The effects of changes in the trade structure are exactly opposite. That is, negative for the US, East Asia and the EU, positive for China and the RoW. This reflects the tendency in trade. Consumers buy final products and producers buy intermediate inputs, and they all move away from the standard suppliers (US and EU) towards emerging and developing countries (in particular China and the RoW). Cheap labor in emerging and developing countries led producers in the US and Europe to internationally outsource (or offshore) parts of the production processes. This is why in particular China is viewed as "the factory of the world".

3.4. Robustness analyses

3.4.1. Price effects

This section compares the results (in Fig. 1) from tables in the 2016 release in previous year's prices (indicated as 2016PYP) with the results when using tables in current prices (indicated as 2016CURR). The results are expected to differ because (*i*) variables in values (which are sensitive to price changes) are used and (*ii*) coefficients (which have TJ per million USD as their dimension) are used.

We hypothesize that the effects of changes in final demands per capita will be stronger (i.e. larger positive) for 2016CURR than for 2016PYP. If prices of final demands increase in addition to increasing final demand volumes, the values of final demands increase more than the volumes do. The final demands and the year-to-year changes are therefore larger in 2016CURR than in 2016PYP. The positive effects of final demand increases will thus be larger when calculated with 2016CURR than with 2016PYP.

A second hypothesis is that the negative effects for technology are stronger. If the energy input coefficients (e.g. energy use per USD of output) decrease, price increases of the outputs induce an additional reduction. The annual changes in the energy input coefficients are thus negative in 2016PYP and more negative in 2016CURR, and the same applies to the resulting effects.

The contributions of the other drivers are not expected to differ substantially. Note that the dimension of final demands is USD per capita and the dimension of energy input coefficients is megajoule per USD. Most of the other drivers are based on shares or coefficients without a dimension (USD of inputs per USD of output). They are therefore less sensitive to price changes.

As a first observation, note that the scale on the vertical axis of Fig. 3 differs from the scale in Fig. 1. The total increase in RE use over the period 2000–2014 is the same of course (22.1 EJ) in both figures. However, there are enormous differences in the levels of the contributions of two drivers. The effect (on the change in global RE use) of changes in final demands per capita is more than 125% larger in 2014 when price changes are included (in 2016CURR) than for just volume changes (in 2016PYP). For the effect of technology changes, 2016PYP in 2014 is even 175% larger than 2016PYP due to price changes.

The differences are very small for the other driver (i.e. trade) that is affected by price changes. This effect is based on the ratio of domestically produced inputs versus imported inputs. If prices change differently abroad than at home, the ratio calculated with PYP tables will differ from the ratio calculated with CURR tables. Also the contribution of changes in trade structure will then differ between PYP and CURR. The results for the contribution of this driver are very similar in Figs. 1 and 3, which suggests that the relative price changes have been similar across countries.

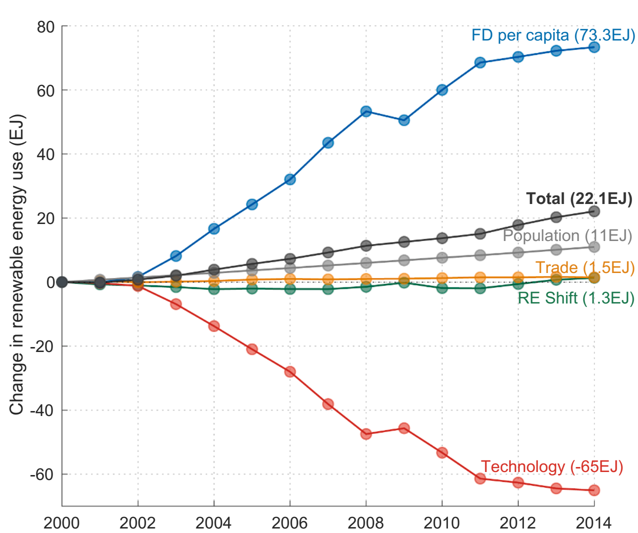

Fig. 3. Cumulative change in global renewable energy use by driver, 2000–2014 in current prices. *Notes*: See the notes to Fig. 1 for an explanation of the effects.

The remaining two drivers (population and RE shift) yield exactly the same results. Population is measured in numbers of people and this measurement is not sensitive to price changes. RE shift is the ratio of RE use in EJ and total energy use in EJ, and the measurement of both is insensitive to prices. The findings are qualitatively in line with the expectations, quantitatively they clearly indicate that correcting for prices can make a huge difference (e.g. more than doubling two of the outcomes).

The second observation is that the effect of changes in final demands per capita and of technology changes are opposed. Note that (*i*) the effects for some other drivers are exactly the same for the CURR and PYP calculations, (*ii*) for some other drivers the effects are approximately the same, and (*iii*) the sum of all effects is fixed (+22.1 EJ). Therefore, the *net* effect of the remaining drivers (which are changes in final demands per capita and technology changes) must be very similar in Figs. 1 and 3. Indeed the *net* effect is +8.6 EJ when using the tables in previous year's prices and it is +8.3 EJ when using current prices.

The third observation is that the results for 2009 sketch a different picture. The 2016CURR results indicate that the technology changes caused an increase in global RE use, after years of continuous decline. The 2016PYP results in Fig. 1 indicated an ongoing (although perhaps smaller) decline. This suggests that prices (at least for some very energy intensive products) have decreased in 2009.

3.4.2. Database differences

The WIOD database knows two releases, one in 2013 and one in 2016. The 2013 release covered 41 countries (the then 27 EU members states, 13 other major economies, and the Rest of the World aggregate) for the period 1995–2009. The tables are based on data for 35 industries, classified according to the International Standard Industrial Classification revision 3 (two-digit ISIC Rev. 3 level). The tables follow the principles of the SNA 1993. The 2016 release covered 44 countries (28 EU members states, 15 other major economies, and the Rest of the World aggregate) for the period 2000–2014. The tables are based on data for 56 industries and products that are classified according to the International Standard Industrial Classification revision 4 (ISIC Rev. 4). The tables are in line with the SNA 2008. Both releases include tables in current prices and in previous year's prices.

This section compares four sets of results for the years 2000–2009. These are the overlapping years in the 2013 and 2016 release of the WIOD. The results are obtained from: tables from the 2013 release (2013PYP and 2013CURR) and tables from the 2016 release (2016PYP and 2016CURR). The comparisons between the 2013 and 2016 releases tell us something about the consequences of using different tables (but both in previous year's prices or both in current prices). For example, the country and the industry classification have become more detailed in the 2016 release, and the set-up of the tables is different (changing from the SNA 1993 to the SNA 2008, with a different treatment of processing trade).

Observe that the results in Fig. 4 are very similar. This holds for Fig. 4a and b for PYP results and for Fig. 4c and d for CURR findings. Note that Fig. 4b with 2016PYP gives the same results as in Fig. 1, but rescaled such that 2000 = 0. (The same holds for Figs. 3 and 4d.) The differences in the findings are small, but it should be stressed that the focus is on RE use at the *global* level. The differences may be more substantial when looking at a less aggregated level. For example, when looking at the results for separate countries or even single industries in separate countries. Also the differences between PYP and CURR results (which were reported in Section 3.3 for 2000–2014) are observed here for 2000–2009: in Fig. 4a and c for the 2013 release and in Fig. 4b and d for the 2016 release.

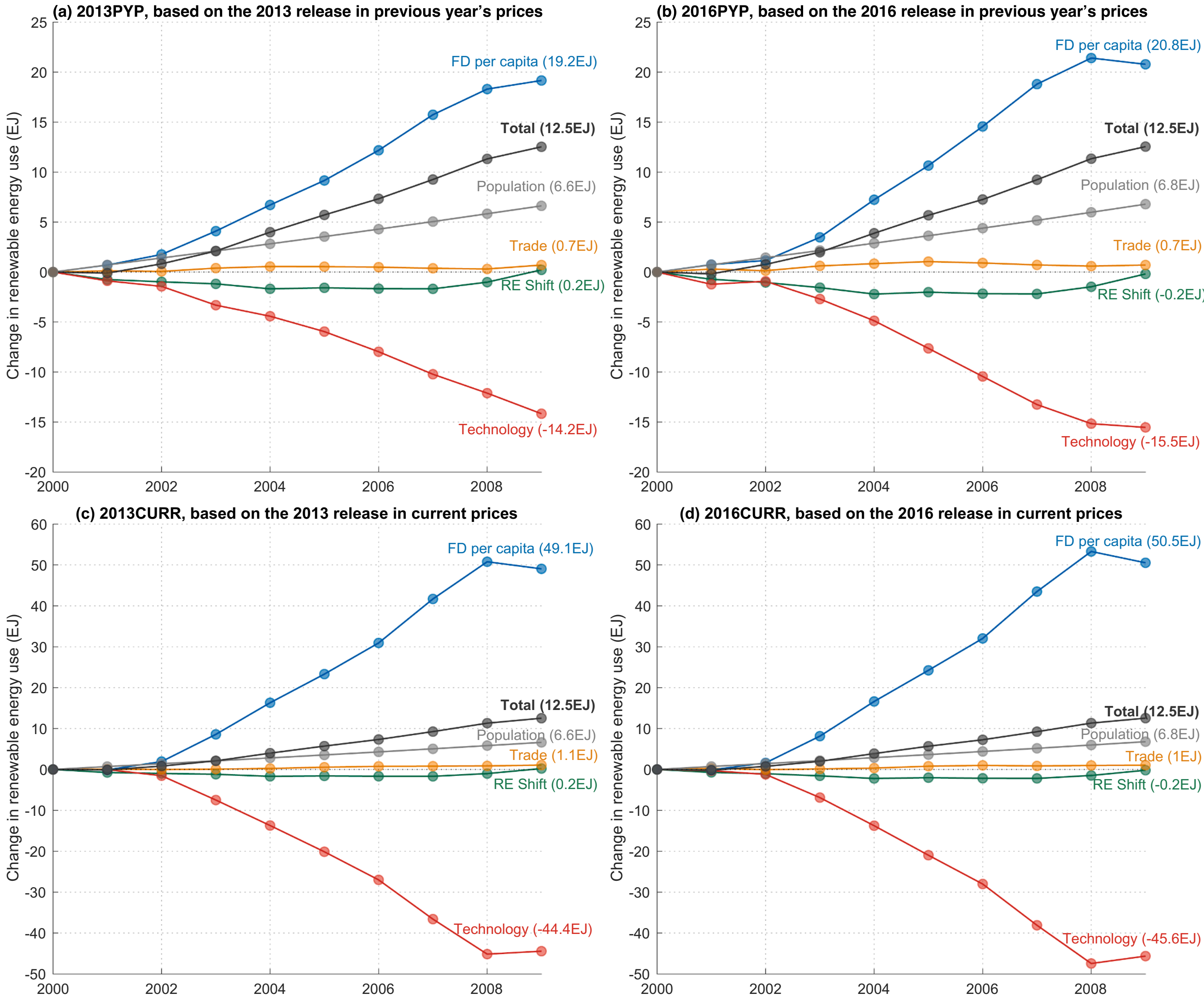

Fig. 4. Cumulative change in global renewable energy use by driver for the overlapping period 2000–2009 in four versions of WIOD. *Notes*: See the notes to Fig. 1 for an explanation of the effects.

4. Conclusions

This paper developed a new variant of the structural decomposition analysis that quantifies the contribution of energy transition to the change in renewable energy (RE) use. The other drivers of this change are: changes in the consumption bundle per capita; population changes; technology changes, including changes in energy efficiency; and changes in the trade structure. The empirical analysis encompassed 43 countries plus the Rest of the World (RoW) and considered the change in RE use at the global level and in territorial RE use at the country level. The change in RE use was between 2000 and 2014, and all drivers were global changes.

At the global level, RE use has grown with 2.3% per year (2.1% in the period 2000–2007 and 2.5% in the period 2007–2014). Energy transition itself (measured as the share of RE use in total energy use) was positive over the period. This means that RE use grew more than non-RE did. The transition started to take off only in the second sub-period 2007–2014. This was observed in particular for RE used by industries in their production processes. For energy used directly by households, RE use growth slowed down during the second sub-period, implying that non-RE use grew more than did RE use.

Not surprisingly, the contribution of energy transition to global RE use was small but positive. Closer inspection at the country level, however, showed that energy transition contributed positively to the RE use of the EU, the US and East Asia, and negatively to the RE use of China, India and the RoW.

Despite the enormous increase in trade, the contribution of changes in the trade structure to global RE use was small. It matters how much producers and consumers use of a certain product, not where this product is made. As was the case for global emissions (see [11]), the location of production and consumption only plays a minor role for *global* RE use. Location does play a role though at the country level. Changes in the trade structure increased RE use in China and RoW. This is because all over the world producers and consumers have shifted towards buying intermediate and final products from China and RoW. In contrast, they have shifted away from buying these products in the US, the EU and East Asia. Changes in the trade structure thus decreased their RE use.

Acknowledgements

We would like to thank two referees for their helpful comments.

Appendix A

A.1. The global multiregional input–output (GMRIO) framework

Suppose there are N countries, each with n industries.[2] The $Nn \times Nn$ matrix $\mathbf{Z}$ of intermediate deliveries, the $Nn \times N$ matrix $\mathbf{F}$ of final demands, and the Nn-element output vector $\mathbf{x}$ are (in partitioned form) given by

$$\mathbf{Z} = \begin{bmatrix} \mathbf{Z}^{11} & \cdots & \mathbf{Z}^{1R} & \cdots & \mathbf{Z}^{1N} \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ \mathbf{Z}^{R1} & \cdots & \mathbf{Z}^{RR} & \cdots & \mathbf{Z}^{RN} \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ \mathbf{Z}^{N1} & \cdots & \mathbf{Z}^{NR} & \cdots & \mathbf{Z}^{NN} \end{bmatrix}, \quad \mathbf{F} = \begin{bmatrix} \mathbf{f}^{11} & \cdots & \mathbf{f}^{1R} & \cdots & \mathbf{f}^{1N} \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ \mathbf{f}^{R1} & \cdots & \mathbf{f}^{RR} & \cdots & \mathbf{f}^{RN} \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ \mathbf{f}^{N1} & \cdots & \mathbf{f}^{NR} & \cdots & \mathbf{f}^{NN} \end{bmatrix}, \quad \mathbf{x} = \begin{pmatrix} \mathbf{x}^1 \\ \vdots \\ \mathbf{x}^R \\ \vdots \\ \mathbf{x}^N \end{pmatrix} \tag{2}$$

Element z_{ij}^{RS} of the $n \times n$ matrix $\mathbf{Z}^{RS}$ gives the money value (in million dollars, m$) of intermediate deliveries from industry i in country R to industry j in country S. Element f_i^{RS} of the n-element vector $\mathbf{f}^{RS}$ gives the deliveries from industry i in country R for final demands in country S. Final demands are the demand for final products and includes household consumption, private investment, government expenditures (for consumption and investments), and changes in stocks and inventories. Element x_i^R of the n-element vector $\mathbf{x}^R$ gives the output of industry i in country R. The Nn accounting equations are given by $\mathbf{x} = \mathbf{Z}\mathbf{e}_{Nn} + \mathbf{F}\mathbf{e}_N$, where $\mathbf{e}_{Nn}$ is the Nn-element summation vector consisting of ones.

The $Nn \times Nn$ matrix with input coefficients is given by $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$, implying $\mathbf{A}^{RS} = \mathbf{Z}^{RS}(\hat{\mathbf{x}}^S)^{-1}$ or $a_{ij}^{RS} = z_{ij}^{RS}/x_j^S$ which gives the intermediate inputs per unit of the receiving industry's output. Substituting $\mathbf{Z}\mathbf{e}_{Nn} = \mathbf{A}\mathbf{x}$ into the accounting equations yields $\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{F}\mathbf{e}_N$. This can be rewritten as

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{F}\mathbf{e}_N = \mathbf{L}\mathbf{F}\mathbf{e}_N \tag{3}$$

where the $Nn \times Nn$ matrix $\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse, which (in its partitioned form) is given by

$$\mathbf{L} = \begin{bmatrix} \mathbf{L}^{11} & \cdots & \mathbf{L}^{1R} & \cdots & \mathbf{L}^{1N} \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ \mathbf{L}^{R1} & \cdots & \mathbf{L}^{RR} & \cdots & \mathbf{L}^{RN} \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ \mathbf{L}^{N1} & \cdots & \mathbf{L}^{NR} & \cdots & \mathbf{L}^{NN} \end{bmatrix} \tag{4}$$

Energy use by industry is given by

$$\bar{\mathbf{r}} = \begin{pmatrix} \bar{\mathbf{r}}^1 \\ \vdots \\ \bar{\mathbf{r}}^R \\ \vdots \\ \bar{\mathbf{r}}^N \end{pmatrix} \text{ and } \mathbf{r} = \begin{pmatrix} \mathbf{r}^1 \\ \vdots \\ \mathbf{r}^R \\ \vdots \\ \mathbf{r}^N \end{pmatrix} \tag{5}$$

where $\bar{\mathbf{r}}$ is an Nn-element vector and element $\bar{r}_i^R$ of the n-element vector $\bar{\mathbf{r}}^R$ gives the total energy use by industry i in country R. In the same way does the vector $\mathbf{r}$ give the renewable energy use by industry. The direct energy use by households is given by

$$\bar{\mathbf{h}} = \begin{pmatrix} \bar{h}^1 \\ \vdots \\ \bar{h}^R \\ \vdots \\ \bar{h}^N \end{pmatrix} \text{ and } \mathbf{h} = \begin{pmatrix} h^1 \\ \vdots \\ h^R \\ \vdots \\ h^N \end{pmatrix} \tag{6}$$

where $\bar{\mathbf{h}}$ is an N-element vector and element $\bar{h}^R$ gives the total energy used directly by households in country R. In the same way does the vector $\mathbf{h}$ give the renewable energy used directly by households. The vectors with all energy use are given by

$$\bar{\mathbf{c}} = \begin{pmatrix} \bar{c}^1 \\ \vdots \\ \bar{c}^R \\ \vdots \\ \bar{c}^N \end{pmatrix} \text{ and } \mathbf{c} = \begin{pmatrix} c^1 \\ \vdots \\ c^R \\ \vdots \\ c^N \end{pmatrix} \tag{7}$$

[2] Matrices are in bold capital letters (e.g. $\mathbf{Z}$ or $\mathbf{Z}^{RS}$), vectors are in bold lower case letters (e.g. $\mathbf{x}$ or $\mathbf{x}^R$), and scalars are in italicized letters (e.g. n, x_i^R, or z_{ij}^{RS}). A circumflex (or "hat") is used to indicate a diagonal matrix (e.g. $\hat{\mathbf{x}}$ or $\hat{\mathbf{x}}^R$) and an apostrophe (or "dash") is used for transposition (e.g. $\mathbf{x}'$ or $(\mathbf{x}^R)'$).

where $\bar{\mathbf{c}}$ is an N-element vector and element $\bar{c}^R$ gives all energy used in country R. It is the sum of the total energy used in production and the total energy used directly by households. That is, $\bar{c}^R = \mathbf{e}_n^{'}\bar{\mathbf{r}}^R = \sum_i \bar{r}_i^R + \bar{h}^R$. In the same way does the vector $\mathbf{c}$ give all use of renewable energy,

$$c^R = \mathbf{e}_n^{'}\mathbf{r}^R = \sum_i r_i^R + h^R \tag{8}$$

Note that this equation can be written as

$$\mathbf{c} = \mathbf{E}\mathbf{r} + \mathbf{h} \tag{9}$$

with the $N \times Nn$ matrix $\mathbf{E}$ given by

$$\mathbf{E} = \begin{bmatrix} \mathbf{e}_n' & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ 0 & \cdots & \mathbf{e}_n' & \cdots & 0 \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \mathbf{e}_n' \end{bmatrix} \tag{10}$$

A.2. Renewable energy use in production

The renewable energy input coefficients are given by

$$\mathbf{q} = \hat{\mathbf{x}}^{-1}\mathbf{r} = \begin{pmatrix} \mathbf{q}^1 \\ \vdots \\ \mathbf{q}^R \\ \vdots \\ \mathbf{q}^N \end{pmatrix} = \begin{pmatrix} (\hat{\mathbf{x}}^1)^{-1}\mathbf{r}^1 \\ \vdots \\ (\hat{\mathbf{x}}^R)^{-1}\mathbf{r}^R \\ \vdots \\ (\hat{\mathbf{x}}^N)^{-1}\mathbf{r}^N \end{pmatrix} \tag{11}$$

or $q_i^R = r_i^R/x_i^R$, which gives the use of renewable energy in industry i in country R per unit of this industry's output. Next the use of renewable energy is taken as a share of total energy use. That is

$$q_i^R = \frac{r_i^R}{x_i^R} = \frac{r_i^R}{\bar{r}_i^R}\frac{\bar{r}_i^R}{x_i^R} = m_i^R \bar{q}_i^R \tag{12}$$

where m_i^R gives the renewable energy use as a share of total energy use in industry i in country R and $\bar{q}_i^R$ gives the input coefficient for total energy use (i.e. the total use of energy in industry i in country R per unit of this industry's output).

From (11) it follows that $\mathbf{r} = \hat{\mathbf{q}}\mathbf{x}$ and $\mathbf{E}\mathbf{r}$ in (9) can be written as

$$\mathbf{E}\mathbf{r} = \begin{bmatrix} \mathbf{e}_n' & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ 0 & \cdots & \mathbf{e}_n' & \cdots & 0 \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \mathbf{e}_n' \end{bmatrix}\hat{\mathbf{q}}\mathbf{x} = \begin{bmatrix} (\mathbf{q}^1)' & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ 0 & \cdots & (\mathbf{q}^R)' & \cdots & 0 \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & (\mathbf{q}^N)' \end{bmatrix}\mathbf{x} = \mathbf{Q}\mathbf{x} \tag{13}$$

Define

$$\mathbf{Q} = \begin{bmatrix} (\mathbf{q}^1)' & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ 0 & \cdots & (\mathbf{q}^R)' & \cdots & 0 \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & (\mathbf{q}^N)' \end{bmatrix}, \text{ and}$$

$$\mathbf{M} = \begin{bmatrix} (\mathbf{m}^1)' & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ 0 & \cdots & (\mathbf{m}^R)' & \cdots & 0 \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & (\mathbf{m}^N)' \end{bmatrix} \tag{14}$$

and define $\bar{\mathbf{Q}}$ in the same way. Equation (12) can in matrix notation be written as $\mathbf{Q} = \mathbf{M} \otimes \bar{\mathbf{Q}}$, where $\otimes$ indicates the Hadamard product (of elementwise multiplication) of two matrices.

Using (3), this implies

$$\mathbf{E}\mathbf{r} = \mathbf{Q}\mathbf{x} = (\mathbf{M} \otimes \bar{\mathbf{Q}})\mathbf{x} = (\mathbf{M} \otimes \bar{\mathbf{Q}})\mathbf{L}\mathbf{F}\mathbf{e}_N \tag{15}$$

A.3. The final demands

The final demands can be written as the multiplication of four components. That is,

$$f_i^{RS} = \frac{f_i^{RS}}{\sum_R f_i^{RS}}\frac{\sum_R f_i^{RS}}{\sum_j \sum_R f_j^{RS}}\frac{\sum_j \sum_R f_j^{RS}}{p^S}p^S = t_i^{RS} g_i^S d^S p^S \tag{16}$$

The final demand (f_i^{RS}) of good i produced in country R by "consumers" in country S is split into (*i*) the population p^S of country S, (*ii*) total "consumption" per capita ($d^S = \sum_j \sum_R f_j^{RS} / p^S$) in country S, (*iii*) the consumption of good i as a share of total consumption in country S ($g_i^S = \sum_R f_i^{RS} / \sum_j \sum_R f_j^{RS}$), reflecting the commodity mix of the consumption bundle in country S, and (*iv*) the share of the consumption of good i by country S that is produced in country R ($t_i^{RS} = f_i^{RS} / \sum_R f_i^{RS}$), reflecting the imports shares of final products in case $R \neq S$. In matrix form

$$\mathbf{F} = \begin{bmatrix} \mathbf{f}^{11} & \cdots & \mathbf{f}^{1R} & \cdots & \mathbf{f}^{1N} \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ \mathbf{f}^{R1} & \cdots & \mathbf{f}^{RR} & \cdots & \mathbf{f}^{RN} \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ \mathbf{f}^{N1} & \cdots & \mathbf{f}^{NR} & \cdots & \mathbf{f}^{NN} \end{bmatrix} = \left(\begin{bmatrix} \mathbf{t}^{11} & \cdots & \mathbf{t}^{1R} & \cdots & \mathbf{t}^{1N} \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ \mathbf{t}^{R1} & \cdots & \mathbf{t}^{RR} & \cdots & \mathbf{t}^{RN} \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ \mathbf{t}^{N1} & \cdots & \mathbf{t}^{NR} & \cdots & \mathbf{t}^{NN} \end{bmatrix} \otimes \begin{bmatrix} \mathbf{g}^{1} & \cdots & \mathbf{g}^{R} & \cdots & \mathbf{g}^{N} \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ \mathbf{g}^{1} & \cdots & \mathbf{g}^{R} & \cdots & \mathbf{g}^{N} \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ \mathbf{g}^{1} & \cdots & \mathbf{g}^{R} & \cdots & \mathbf{g}^{N} \end{bmatrix} \right) \times$$

$$\begin{bmatrix} d^1 & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ 0 & \cdots & d^R & \cdots & 0 \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & d^N \end{bmatrix} \begin{bmatrix} p^1 & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ 0 & \cdots & p^R & \cdots & 0 \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & p^N \end{bmatrix} = (\mathbf{T} \otimes \mathbf{G})\hat{\mathbf{d}}\hat{\mathbf{p}} \tag{17}$$

Note that $\mathbf{T}$ and $\mathbf{G}$ are $Nn \times N$ matrices and $\hat{\mathbf{d}}$ and $\hat{\mathbf{p}}$ are $N \times N$ matrices, which means that $\mathbf{F}\mathbf{e}_N = (\mathbf{T} \otimes \mathbf{G})\hat{\mathbf{d}}\mathbf{p}$. Eq. (15) then becomes

$$\mathbf{E}\mathbf{r} = (\mathbf{M} \otimes \bar{\mathbf{Q}})\mathbf{L}(\mathbf{T} \otimes \mathbf{G})\hat{\mathbf{d}}\mathbf{p} \tag{18}$$

A.4. Renewable energy directly used by households

The second component in Eq. (9) for renewable energy use, is given by the vector $\mathbf{h}$. Similar to what was done for the final demands, the renewable energy directly used by households can be expressed as the multiplication of four components. That is,

$$h^S = \frac{h^S}{\bar{h}^S} \frac{\bar{h}^S}{\sum_j \sum_R f_j^{RS}} \frac{\sum_j \sum_R f_j^{RS}}{p^S} p^S = u^S w^S d^S p^S \tag{19}$$

where for country S: (*i*) p^s gives the population, (*ii*) d^s the consumption per capita, (*iii*) w^S the total (i.e. renewable and non-renewable) energy used directly by households as a share of their total consumption, and (*iv*) u^S the share of renewable energy in the total energy directly used by households. Equation (19) implies that $\mathbf{h} = \hat{\mathbf{u}}\hat{\mathbf{w}}\hat{\mathbf{d}}\mathbf{p}$.

In conclusion, the N-element vector $\mathbf{c}$ in (9) with the total energy use per country can be written as

$$\mathbf{c} = \mathbf{E}\mathbf{r} + \mathbf{h} = (\mathbf{M} \otimes \bar{\mathbf{Q}})\mathbf{L}(\mathbf{T} \otimes \mathbf{G})\hat{\mathbf{d}}\mathbf{p} + \hat{\mathbf{u}}\hat{\mathbf{w}}\hat{\mathbf{d}}\mathbf{p} \tag{20}$$

At this moment, the following nine components have been used:

- the $N \times Nn$ matrix $\mathbf{M}$ with elements m_i^R indicating the renewable energy use as a share of total energy use in industry i in country R;
- the $N \times Nn$ matrix $\bar{\mathbf{Q}}$ with elements $\bar{q}_i^R$ indicating the input coefficient for total energy use (i.e. the total use of energy in industry i in country R per unit of this industry's output);
- the $Nn \times Nn$ matrix $\mathbf{L}$ (the Leontief inverse) with elements l_{ij}^{RS} indicating the amount of output that needs to be produced in industry i in country R to satisfy one unit of final demand for product j from country S;
- the $Nn \times N$ matrix $\mathbf{T}$ with elements t_i^{RS} indicating the share of the consumption of good i by country S that is produced in country R, reflecting imports of final products if $R \neq S$;
- the $Nn \times N$ matrix $\mathbf{G}$ with elements g_i^S indicating the consumption of good i as a share of total consumption in country S, reflecting the commodity mix of the consumption bundle in country S;
- the N-element vector $\mathbf{d}$ with elements d^S indicating total final demand ("consumption") per capita in country S;
- the N-element vector $\mathbf{p}$ with elements p^S indicating the population in country S;
- the N-element vector $\mathbf{u}$ with elements u^S indicating the share of renewable energy in the total energy directly used by households; and
- the N-element vector $\mathbf{w}$ with elements w^S indicating the total (i.e. renewable and non-renewable) energy used directly by households as a share of their total consumption.

A.5. Preliminary decomposition forms

This study applies a structural decomposition analysis (SDA) to renewable energy (RE) use. The idea is to break down the change in RE use into the changes in the underlying components. For example, the change in RE use is due to the change in RE use in the production process ($(\mathbf{M} \otimes \bar{\mathbf{Q}})\mathbf{L}(\mathbf{T} \otimes \mathbf{G})\hat{\mathbf{d}}\mathbf{p}$) and the change in RE directly used by households. The change in $(\mathbf{M} \otimes \bar{\mathbf{Q}})\mathbf{L}(\mathbf{T} \otimes \mathbf{G})\hat{\mathbf{d}}\mathbf{p}$ is then split into the contribution by changes $\Delta\bar{\mathbf{Q}}$ in $\bar{\mathbf{Q}}$, by changes $\Delta\mathbf{M}$ in $\mathbf{M}$, by changes $\Delta\mathbf{L}$ in $\mathbf{L}$, and so forth. Dietzenbacher and Los [54] addressed the issue that decomposition forms are not unique. As a matter of fact, in the case of k components, the number of equivalent decomposition forms amounts to k! An SDA of (20) involves nine components and thus 362,880 equivalent decomposition forms. Dietzenbacher and Los [54] proposed to take the unweighted average and also showed that this average is approximated well by the average of two so-called polar forms.

Consider the change in RE use at the country level between two points in time, say 0 and 1. That is, $\Delta\mathbf{c} = \mathbf{c}_1 - \mathbf{c}_0$ and $\mathbf{c} = \mathbf{E}\mathbf{r} + \mathbf{h} = (\mathbf{M} \otimes \bar{\mathbf{Q}})\mathbf{L}(\mathbf{T} \otimes \mathbf{G})\hat{\mathbf{d}}\mathbf{p} + \hat{\mathbf{u}}\hat{\mathbf{w}}\hat{\mathbf{d}}\mathbf{p}$. The first polar decomposition (indicated by the subscript a) is given by

$$\Delta \mathbf{c}_a = (\Delta\mathbf{M} \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1 + (\mathbf{M}_0 \otimes \Delta\bar{\mathbf{Q}})\mathbf{L}_1(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1 + (\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)(\Delta\mathbf{L})(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1 + (\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\Delta\mathbf{T} \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1 + (\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\mathbf{T}_0 \otimes \Delta\mathbf{G})\hat{\mathbf{d}}_1\mathbf{p}_1 + (\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\mathbf{T}_0 \otimes \mathbf{G}_0)(\Delta\hat{\mathbf{d}})\mathbf{p}_1 + (\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0(\Delta\mathbf{p}) + (\Delta\hat{\mathbf{u}})\hat{\mathbf{w}}_1\hat{\mathbf{d}}_1\mathbf{p}_1 + \hat{\mathbf{u}}_0(\Delta\hat{\mathbf{w}})\hat{\mathbf{d}}_1\mathbf{p}_1 + \hat{\mathbf{u}}_0\hat{\mathbf{w}}_0(\Delta\hat{\mathbf{d}})\mathbf{p}_1 + \hat{\mathbf{u}}_0\hat{\mathbf{w}}_0\hat{\mathbf{d}}_0(\Delta\mathbf{p}) \tag{21}$$

The second polar decomposition (indicated by the subscript b) can be derived in a similar fashion, which yields

$$\Delta \mathbf{c}_b = (\Delta\mathbf{M} \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0 + (\mathbf{M}_1 \otimes \Delta\bar{\mathbf{Q}})\mathbf{L}_0(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0 + (\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)(\Delta\mathbf{L})(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0 + (\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\Delta\mathbf{T} \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0 + (\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\mathbf{T}_1 \otimes \Delta\mathbf{G})\hat{\mathbf{d}}_0\mathbf{p}_0 + (\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\mathbf{T}_1 \otimes \mathbf{G}_1)(\Delta\hat{\mathbf{d}})\mathbf{p}_0 + (\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1(\Delta\mathbf{p}) + (\Delta\hat{\mathbf{u}})\hat{\mathbf{w}}_0\hat{\mathbf{d}}_0\mathbf{p}_0 + \hat{\mathbf{u}}_1(\Delta\hat{\mathbf{w}})\hat{\mathbf{d}}_0\mathbf{p}_0 + \hat{\mathbf{u}}_1\hat{\mathbf{w}}_1(\Delta\hat{\mathbf{d}})\mathbf{p}_0 + \hat{\mathbf{u}}_1\hat{\mathbf{w}}_1\hat{\mathbf{d}}_1(\Delta\mathbf{p}) \tag{22}$$

Next, the average of the two polar decompositions is computed

$$\Delta\mathbf{c} = \mathbf{c}_1 - \mathbf{c}_0 = (\mathbf{c}_a + \mathbf{c}_b)/2 \tag{23}$$

A.6. Trade in intermediate inputs

The change ($\Delta\mathbf{L}$) in the Leontief inverse matrix reflects changes in the input coefficients (i.e. changes in $\mathbf{A}$). In its turn, changes in input coefficients may reflect technological changes (e.g. using less steel per car) and/or changes in the trade structure (e.g. using the same amount of steel per car, but substituting US steel for Russian steel). Following Oosterhaven and van der Linden [31], the effect of changes in input coefficients is split in two separate contributions: one due to variations in technology coefficients and the other due to changes in trade coefficients. First, however, it is necessary to express $\Delta\mathbf{L}$ in terms of $\Delta\mathbf{A}$. This can be done as follows

$$\Delta\mathbf{L} = \mathbf{L}_0(\Delta\mathbf{A})\mathbf{L}_1 = \mathbf{L}_1(\Delta\mathbf{A})\mathbf{L}_0 \tag{24}$$

In the expression for $\Delta\mathbf{c}_a$, the contribution for the changes in the Leontief inverse is $(\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)(\Delta\mathbf{L})(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1$. Next, $\Delta\mathbf{L}$ is replaced by $\mathbf{L}_0(\Delta\mathbf{A})\mathbf{L}_1$ which yields

$$(\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)(\Delta\mathbf{L})(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1 = (\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\Delta\mathbf{A})\mathbf{L}_1(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1 = (\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\Delta\mathbf{A})\mathbf{x}_1 \tag{25a}$$

Similarly in $\Delta\mathbf{c}_b$ expression, $\Delta\mathbf{L}$ is replaced by $\mathbf{L}_1(\Delta\mathbf{A})\mathbf{L}_0$ in $(\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)(\Delta\mathbf{L})(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0$ and this yields

$$(\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)(\Delta\mathbf{L})(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0 = (\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\Delta\mathbf{A})\mathbf{L}_0(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0 = (\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\Delta\mathbf{A})\mathbf{x}_0 \tag{25b}$$

In order to isolate the two effects (i.e. attributable to changes in the production technology and to variations in the trade structure) it is necessary to define the technology coefficients matrix $\mathbf{B}$ and the trade coefficients matrix $\mathbf{H}$. The $Nn \times Nn$ matrix $\mathbf{B}$ is given by

$$\mathbf{B} = \begin{bmatrix} \mathbf{B}^1 & \cdots & \mathbf{B}^S & \cdots & \mathbf{B}^N \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ \mathbf{B}^1 & \cdots & \mathbf{B}^S & \cdots & \mathbf{B}^N \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ \mathbf{B}^1 & \cdots & \mathbf{B}^S & \cdots & \mathbf{B}^N \end{bmatrix} \tag{26}$$

with $\mathbf{B}^S = \sum_R \mathbf{A}^{RS}$ and its typical element $b_{ij}^{1S} = b_{ij}^{2S} = \cdots = b_{ij}^{RS} = \sum_R a_{ij}^{RS}$ gives the total amount of input of good i (i.e. irrespective of the origin country R) per unit of output of good j in country S. The share of this amount that originates from country R is given by $h_{ij}^{RS} = a_{ij}^{RS}/b_{ij}^{RS} = a_{ij}^{RS}/\sum_R a_{ij}^{RS}$. Note that these shares indicate import shares when $R \neq S$. This implies that $\mathbf{A} = \mathbf{H} \otimes \mathbf{B}$. The changes in the input coefficients are then decomposed as

$$\Delta\mathbf{A} = \frac{1}{2}(\Delta\mathbf{H}) \otimes (\mathbf{B}_1 + \mathbf{B}_0) + \frac{1}{2}(\mathbf{H}_1 + \mathbf{H}_0) \otimes (\Delta\mathbf{B}) \tag{27}$$

which is substituted into Eqs. (25a) and (25b).

A.7. The final decomposition forms

Combining the building blocks gives the final decomposition for $\Delta\mathbf{c} = \mathbf{c}_1 - \mathbf{c}_0 = (\mathbf{c}_a + \mathbf{c}_b)/2$, where Eqs. (25) and (27) are used to further split the $\Delta\mathbf{L}$ terms. This yields

$$\Delta\mathbf{c} = \frac{1}{2}(\Delta\mathbf{M} \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1 + \frac{1}{2}(\Delta\mathbf{M} \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0 + \tag{28a}$$

$$\frac{1}{2}(\mathbf{M}_0 \otimes \Delta\bar{\mathbf{Q}})\mathbf{L}_1(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1 + \frac{1}{2}(\mathbf{M}_1 \otimes \Delta\bar{\mathbf{Q}})\mathbf{L}_0(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0 + \tag{28b}$$

$$\frac{1}{4}(\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\Delta\mathbf{H}) \otimes (\mathbf{B}_1 + \mathbf{B}_0)\mathbf{x}_1 + \frac{1}{4}(\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\Delta\mathbf{H}) \otimes (\mathbf{B}_1 + \mathbf{B}_0)\mathbf{x}_0 + \tag{28c}$$

$$\frac{1}{4}(\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\mathbf{H}_1 + \mathbf{H}_0) \otimes (\Delta\mathbf{B})\mathbf{x}_1 + \frac{1}{4}(\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\mathbf{H}_1 + \mathbf{H}_0) \otimes (\Delta\mathbf{B})\mathbf{x}_0 + \tag{28d}$$

$$\frac{1}{2}(\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\Delta\mathbf{T} \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1\mathbf{p}_1 + \frac{1}{2}(\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\Delta\mathbf{T} \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0\mathbf{p}_0 + \tag{28e}$$

$$\frac{1}{2}(\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\mathbf{T}_0 \otimes \Delta\mathbf{G})\hat{\mathbf{d}}_1\mathbf{p}_1 + \frac{1}{2}(\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\mathbf{T}_1 \otimes \Delta\mathbf{G})\hat{\mathbf{d}}_0\mathbf{p}_0 + \tag{28f}$$

$$\frac{1}{2}(\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\mathbf{T}_0 \otimes \mathbf{G}_0)(\Delta\hat{\mathbf{d}})\mathbf{p}_1 + \frac{1}{2}(\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\mathbf{T}_1 \otimes \mathbf{G}_1)(\Delta\hat{\mathbf{d}})\mathbf{p}_0 + \tag{28g}$$

$$\frac{1}{2}(\mathbf{M}_0 \otimes \bar{\mathbf{Q}}_0)\mathbf{L}_0(\mathbf{T}_0 \otimes \mathbf{G}_0)\hat{\mathbf{d}}_0(\Delta\mathbf{p}) + \frac{1}{2}(\mathbf{M}_1 \otimes \bar{\mathbf{Q}}_1)\mathbf{L}_1(\mathbf{T}_1 \otimes \mathbf{G}_1)\hat{\mathbf{d}}_1(\Delta\mathbf{p}) + \tag{28h}$$

$$\frac{1}{2}(\Delta\hat{\mathbf{u}})\widehat{\mathbf{w}}_0\hat{\mathbf{d}}_0\mathbf{p}_0 + \frac{1}{2}(\Delta\hat{\mathbf{u}})\widehat{\mathbf{w}}_1\hat{\mathbf{d}}_1\mathbf{p}_1 + \tag{28i}$$

$$\frac{1}{2}\hat{\mathbf{u}}_1(\Delta\widehat{\mathbf{w}})\hat{\mathbf{d}}_0\mathbf{p}_0 + \frac{1}{2}\hat{\mathbf{u}}_0(\Delta\widehat{\mathbf{w}})\hat{\mathbf{d}}_1\mathbf{p}_1 + \tag{28j}$$

$$\frac{1}{2}\hat{\mathbf{u}}_1\widehat{\mathbf{w}}_1(\Delta\hat{\mathbf{d}})\mathbf{p}_0 + \frac{1}{2}\hat{\mathbf{u}}_0\widehat{\mathbf{w}}_0(\Delta\hat{\mathbf{d}})\mathbf{p}_1 + \tag{28k}$$

$$\frac{1}{2}\hat{\mathbf{u}}_1\widehat{\mathbf{w}}_1\hat{\mathbf{d}}_1(\Delta\mathbf{p}) + \frac{1}{2}\hat{\mathbf{u}}_0\widehat{\mathbf{w}}_0\hat{\mathbf{d}}_0(\Delta\mathbf{p}) \tag{28l}$$

The twelve contributions are combined into the following five drivers of change in RE use:

- technological changes, which include changes $\Delta\bar{\mathbf{Q}}$ in the input coefficients for total energy use in (28a); changes $\Delta\mathbf{B}$ in technology coefficients in (28d), and changes $\Delta\widehat{\mathbf{w}}$ in the shares of energy directly used by households in total consumption in (28i);
- changes in trade structure, which include changes $\Delta\mathbf{H}$ in the import shares of intermediate inputs in (28c), and changes $\Delta\mathbf{T}$ in the import shares of final products in (28e);
- changes in final demands per capita, which consists of changes $\Delta\mathbf{d}$ in the total final demand ("consumption") per capita in (28g) and (28k), and changes $\Delta\mathbf{G}$ in the commodity mix of the consumption bundle in (28f);
- changes $\Delta\mathbf{p}$ in population in (28h) and (28l);
- changes in energy transition, which include: changes $\Delta\mathbf{M}$ in the share of renewable energy use in total energy use in (28b) for the production processes; and changes $\Delta\mathbf{u}$ in the share of renewable energy use in total energy use in (28b) for the energy directly used by households.

This decomposition is based on RE use per country as reflected by the N elements of the vector $\mathbf{c} = (\mathbf{M} \otimes \bar{\mathbf{Q}})\mathbf{L}(\mathbf{T} \otimes \mathbf{G})\hat{\mathbf{d}}\mathbf{p} + \hat{\mathbf{u}}\widehat{\mathbf{w}}\hat{\mathbf{d}}\mathbf{p}$. These can also be derived as the rowsums of the $N \times N$ matrix $\mathbf{C} = (\mathbf{M} \otimes \bar{\mathbf{Q}})\mathbf{L}(\mathbf{T} \otimes \mathbf{G})\hat{\mathbf{d}}\hat{\mathbf{p}} + \hat{\mathbf{u}}\widehat{\mathbf{w}}\hat{\mathbf{d}}\mathbf{p}$. The element c_{RS} gives the RE use in country R due to final demand in country S if $R \neq S$ and adds RE directly used by households if $R = S$. The S-th columnsum of matrix $\mathbf{C}$ gives the "RE footprint" of country S, i.e. global use of RE due to the final demands of country S, and may be subjected to an SDA.

A.8. Chaining the results

From 2000 onwards there are annual GMRIO tables in current prices (indicated as CURR) and in previous year's prices (PYP). Following Arto and Dietzenbacher [11], the variable (e.g. the energy input in TJ per million USD of output) in year $t1$ is obtained by using the PYP table (which yields γ_{t1}^{PYP}) and the variable in year $t0$ is obtained by using CP table (which yields γ_{t0}^{CURR}). The change in γ between time $t0$ and $t1$ is given by

$$\Delta\gamma_{t1-t0} = \gamma_{t1}^{PYP} - \gamma_{t0}^{CURR} \tag{29}$$

Because the variable uses the same prices in both cases, the change reflects volume (or true physical) changes only. Similarly, the change between time points $t1$ and $t2$ is

$$\Delta\gamma_{t2-t1} = \gamma_{t2}^{PYP} - \gamma_{t1}^{CURR} \tag{30}$$

The difference between time points $t0$ to $t2$ is now defined by chaining the previous equations

$$\Delta\gamma_{t2-t0} = \Delta\gamma_{t2-t1} + \Delta\gamma_{t1-t0} = (\gamma_{t2}^{PYP} - \gamma_{t1}^{CURR}) + (\gamma_{t1}^{PYP} - \gamma_{t0}^{CURR}) \tag{31}$$

Table B1
List of energy flows and energy commodities used by the IEA.

IEA code	Flow
Combustible Renewables & Wastes	
INDWASTE	Industrial waste
MUNWASTER	Municipal waste (non-renewable)
MUNWASTEN	Municipal waste (renewable)
SBIOMASS	Primary solid biomass
GBIOMASS	Biogases
BIOGASOL	Biogasoline
BIODIESEL	Biodiesels
OBIOLIQ	Other liquid biofuels
RENEWNS	Non-specified primary biomass and waste
CHARCOAL	Charcoal
Electricity & Heat	
HYDRO	Hydroelectric
GEOTHERM	Geothermal
SOLARPV	Solar photovoltaics
SOLARTH	Solar thermal
WIND	Wind power

Table B2
List of energy commodities.

WIOD code	IEA code	Flow
Combustible Renewables & Wastes		
WASTE	INDWASTE + MUNWASTER + MUNWASTEN	Industrial and municipal waste
BIOGASOL	BIOGASOL + OBIOLIQ	Biogasoline and hydrated ethanol
BIODIESEL	BIODIESEL	Biodiesel
BIOGAS	GBIOMASS	Biogas
OTHRENEW	CHARCOAL + RENEWNS + SBIOMASS	Other combustible renewables
Electricity & Heat		
HYDRO	HYDRO	Hydroelectric
GEOTHERM	GEOTHERM	Geothermal
SOLAR	SOLARPV + SOLARTH	Solar
WIND	WIND	Wind

After this deflation process all the yearly variations reflect volume changes and can be summed in order to unveil the long run RE use change. The chaining technique has been applied to the whole time period in this study (i.e. 2000–2014) and to all the components included in the final decomposition expression (28a-28 l).

Appendix B

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